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DESIGN OF HIGH-POWER FAST DIFFUSION-RELEASE ISOL TARGETS FOR RADIOACTIVE ION BEAM GENERATION AT THE RIA: THERMAL MANAGEMENT STUDIES

Y. Zhang, G.D. Alton, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6368

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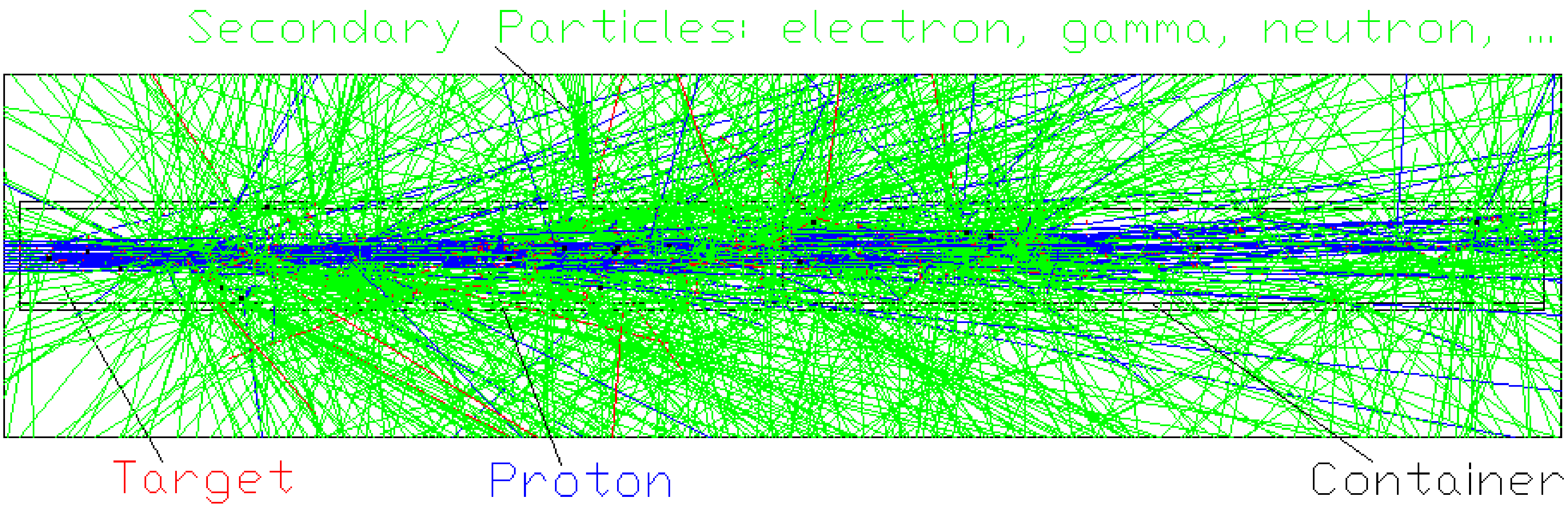
COMPUTER CODES UTILIZED

- **GEANT4**
  - 3D Monte-Carlo code
  - Processes include: electromagnetic, hadronic, decay, transport, ...
  - Tracks all primary and secondary particles: heavy primary projectiles, secondary electrons, gammas neutrons, deuterons, alphas, ...
- **ANSYS**
  - 2D and 3D finite element
  - Thermal loads: heat generation rates, surface radiation rates, boundary temperatures…
  - Temperature dependent material properties: thermal conductivities, specific heats, emissivities, film coefficients….
- **HSC, THERMOCALC, FACTSAGE …**
  - Chemical reactions, vapor pressures and thermal equilibrium compositions…

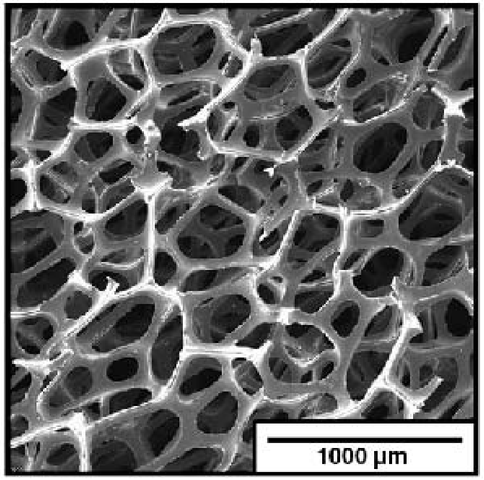
Particle Tracing With GEANT4:
1 GeV Proton Beam Interacting With a UC_2/RVCF Target



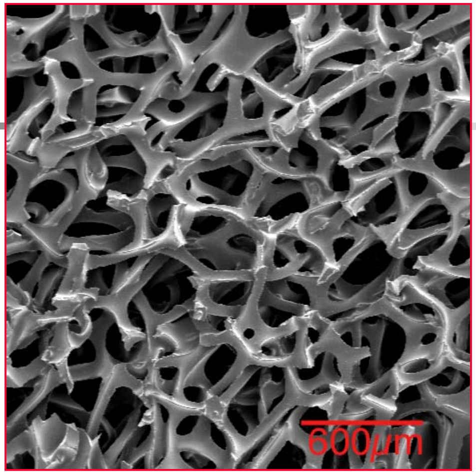
Management of Primary Beam Induced Thermal Affects in Directly Irradiated ISOL Targets

- **Methods for controlling and homogenizing temperature distributions within ISOL targets, directly irradiated with 1 GeV, 400 kW proton beams, must be developed in order to realize the RIB intensity capabilities of the RIA even though ISOL targets with the dimensional and high permeability properties required for fast diffusion release and fast effusive-flow have low thermal conductivities and consequently are necessarily *fragile*.**

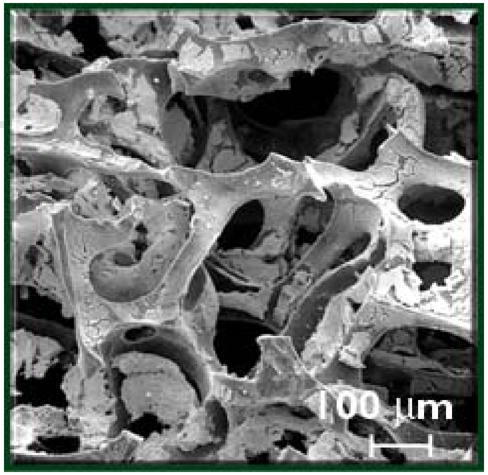
Examples of targets illustrating their fragility!



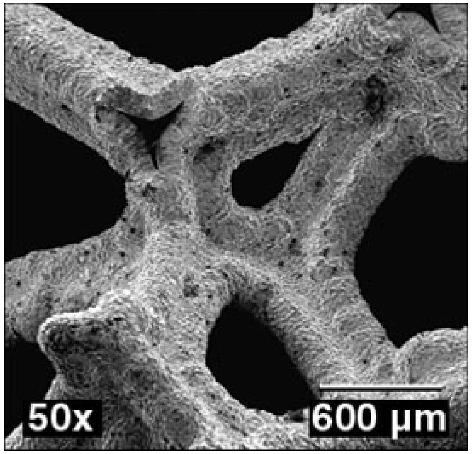
2xRVCF, 0.1 g/cc



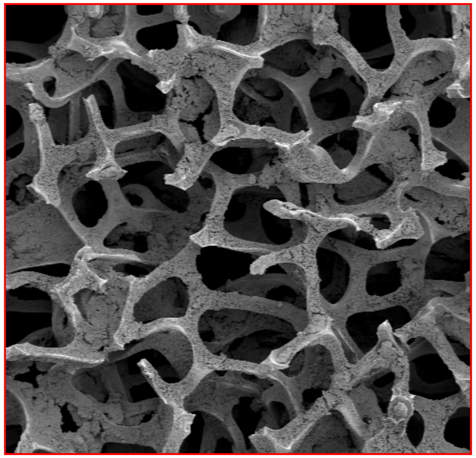
6xRVCF, 0.4 g/cc



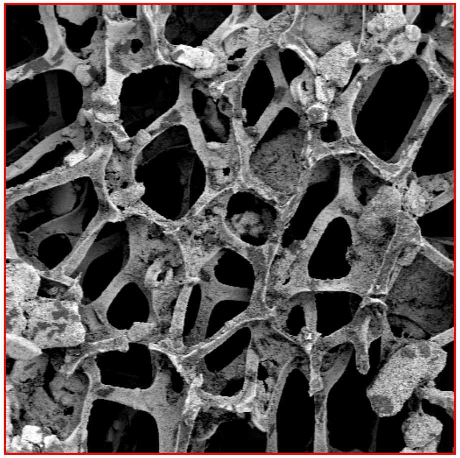
UC_2/2xRVCF, 1.2 g/cc



W/2xRVCF



NbC/2xRVCF



HfO_2/W/2xRVCF

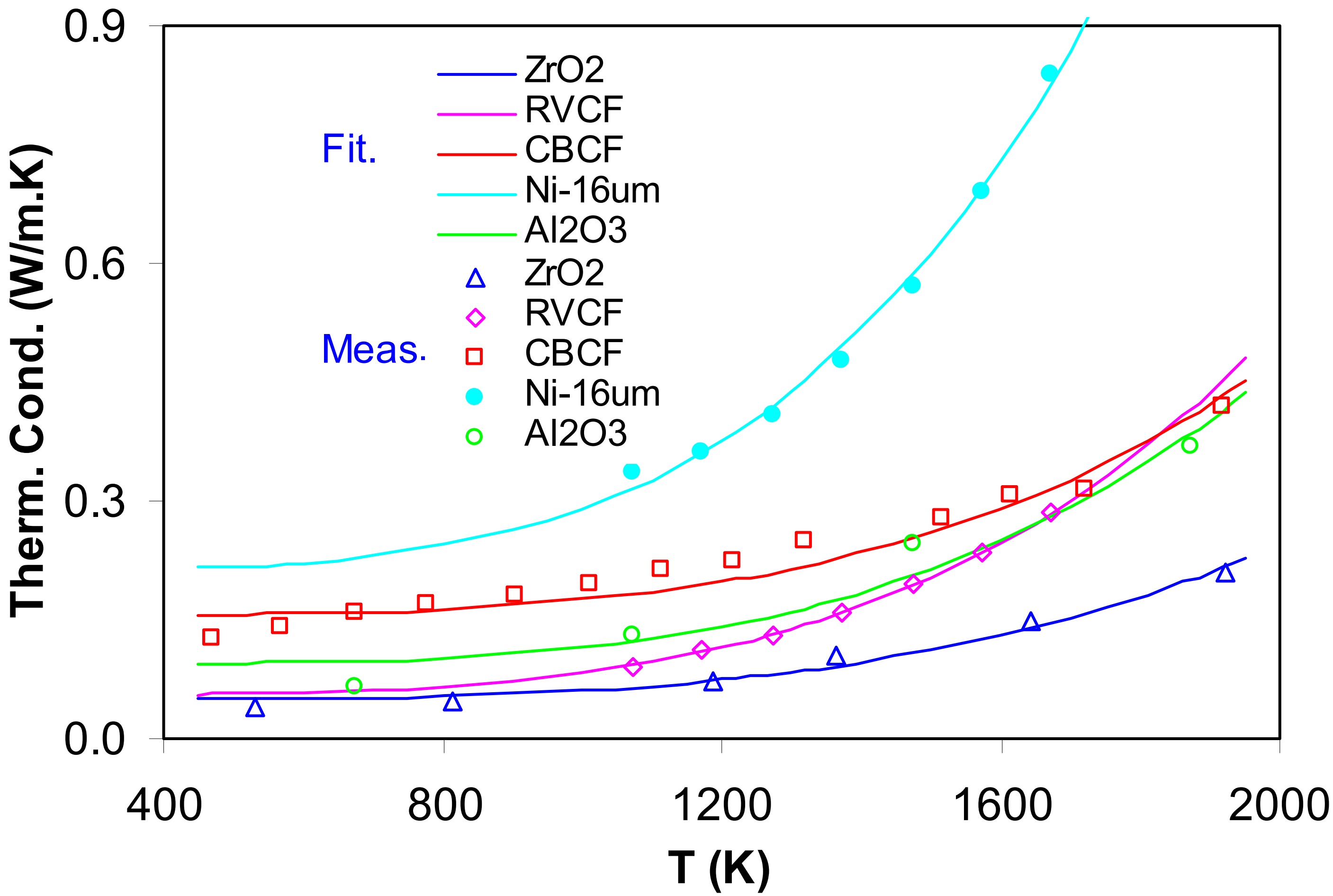
Limiting temperatures of selected candidate target materials in isolation or deposited on substrates

Candidate material	Reaction product	T_{MAX}(K) in isolation	T_{MAX}(K) on *C*	T_{MAX}(K) on *Ta*	T_{MAX}(K) *W*
ThC_2	He → Pa	2923			
UC_2	He → Np	2373			
NbC	He→ N; P→ Mo	2773	2373	2740	2773
TaC	He → W	2893	2573	2793	2903
VC	He → Cr	2203	2073	2183	2178
BeO	He → F	2173	1423	1923	2173
HfO_2	He → Ta	2473	1723	2323	2523
ZrO_2	He→ F; Si→ Nb	2373	1653	2173	2373
CeS	He→ Cl; Cu→Nd	2173			
W	He → Re	3136			
Re	He → Os	2873			

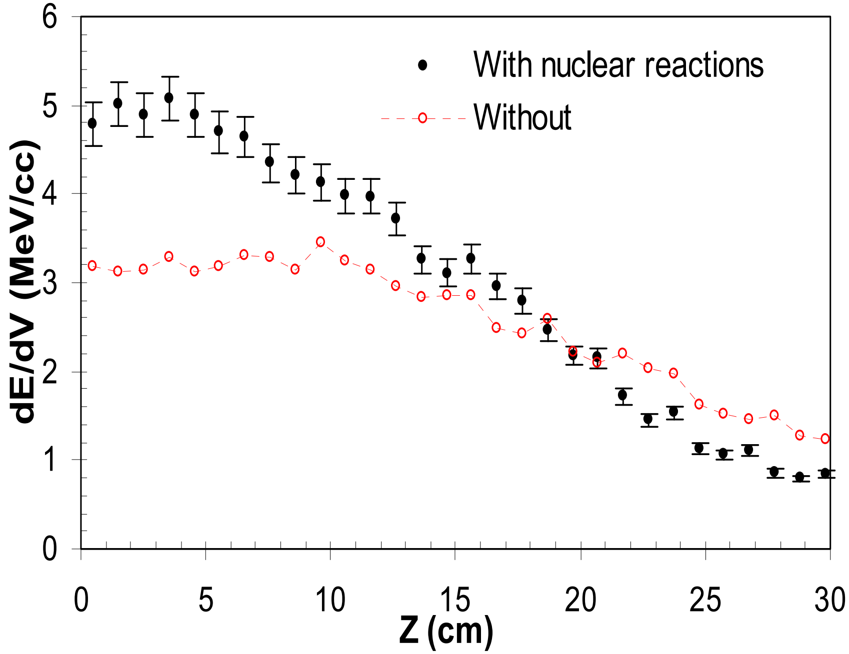
*Limiting temperature calculated at vapor pressure of approximately 2.67×10^{-2} Pa

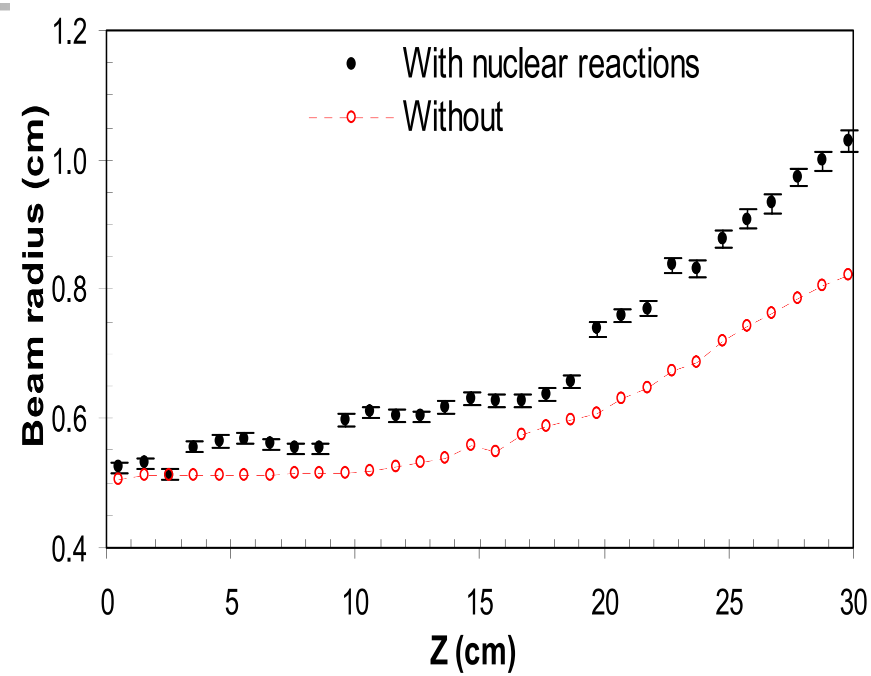
Power Handling Capabilities: Thermal Conductivity

Measured thermal conductivity data for selected low-density fibrous materials.



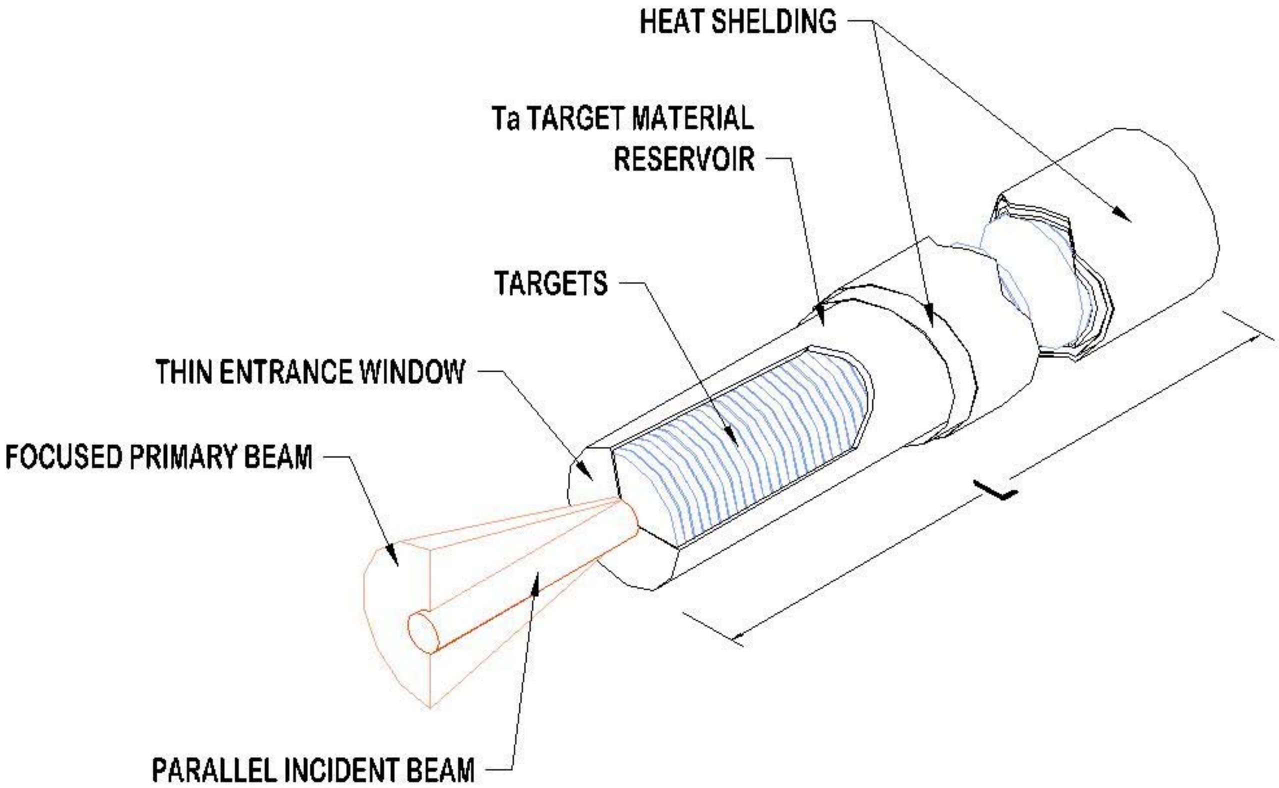
Beam power deposited in high power UC_2 ISOL targets *with* and *without* fission





UC_2/6xRVCF target; density: 4.2 g/cc; 1 GeV proton beam; incident beam diameter: 1 cm.

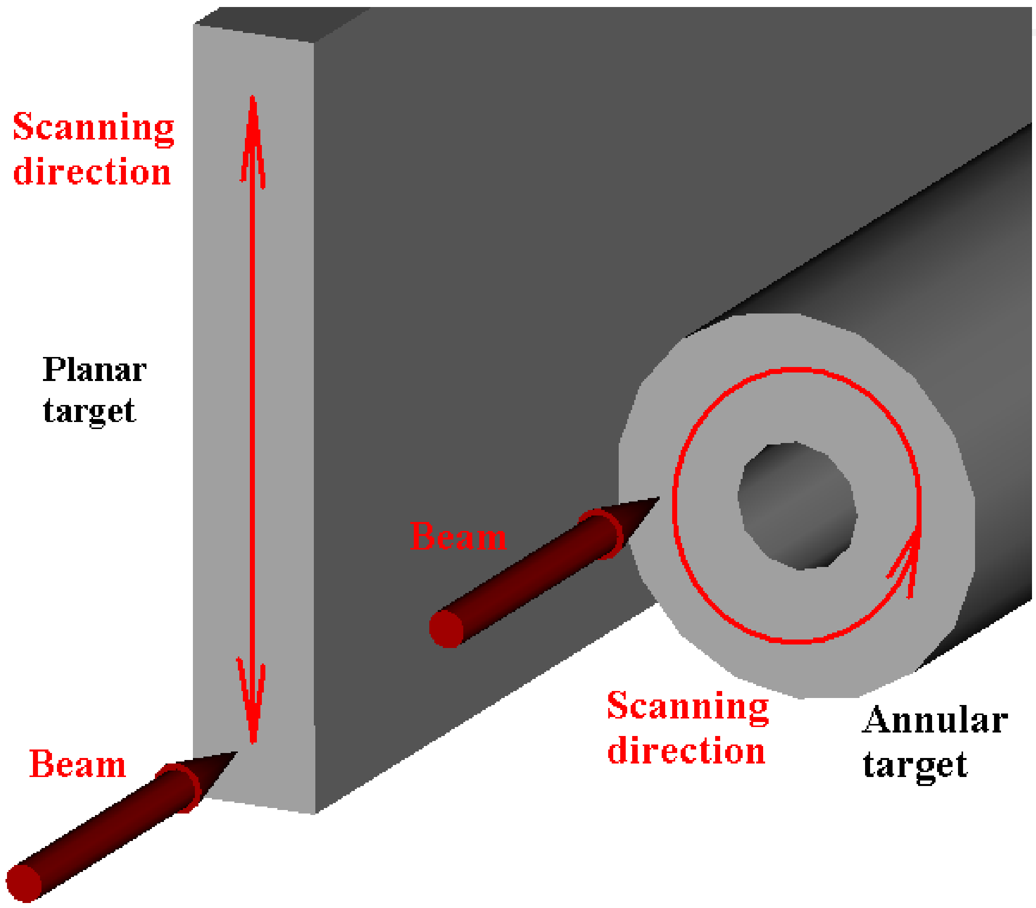
Simulation Studies Of Single Column Targets Subjected to CW Beam Irradiation



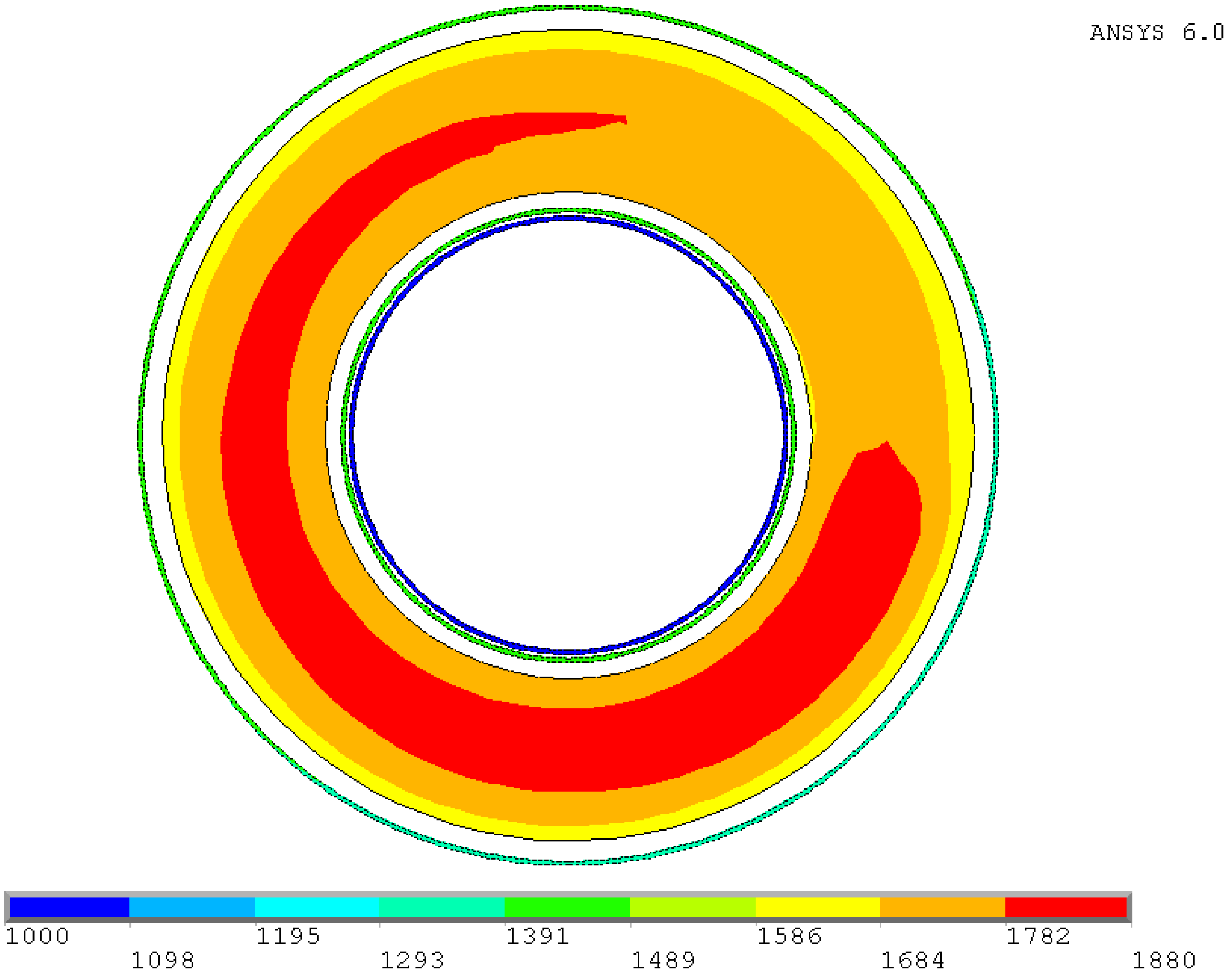
Maximum acceptable beam intensity and deposited beam power in various single-column targets irradiated with CW, 1 GeV proton beams *with* and *without* thermal radiation effects inside the target matrix; Incident beam radius: 1 cm

Target	ϕ (cm)	L (cm)	Without radiation		With internal radiation	
			I (μA)	dP (kW)	I (μA)	dP (kW)
Ta/RVCF	4	80	86	14.2	245	40.0
NbC/RVCF	4	80	64	11.7	120	21.6
BeO/W/RVCF	4	80	66	9.9	100	14.5
ZrO_2	4	80	9	1.3	82	11.8
HfO_2	4	80	7	1.2	80	13.4
UC_2/RVCF	4	80	31	6.2	70	14.0

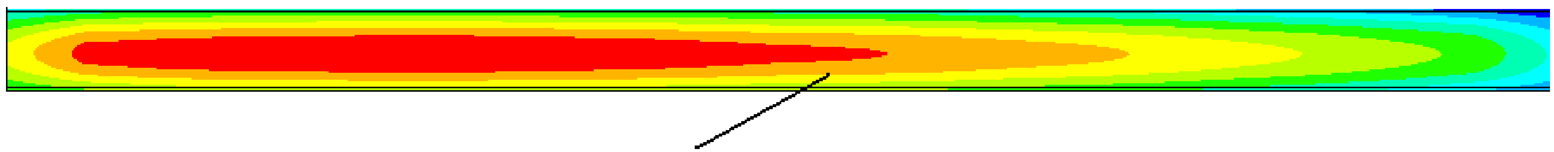
High Power Target Scenarios



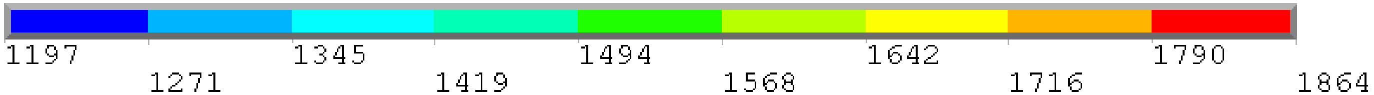
NbC/RVCF composite target, Rin: 6 cm; Rout: 10 cm; Length: 80 cm; Density: 1.2 g/cm^3; 1 GeV, 400 kW annular scanning proton beam; Incident beam radius: 1 cm; Scanning period: 12 s.

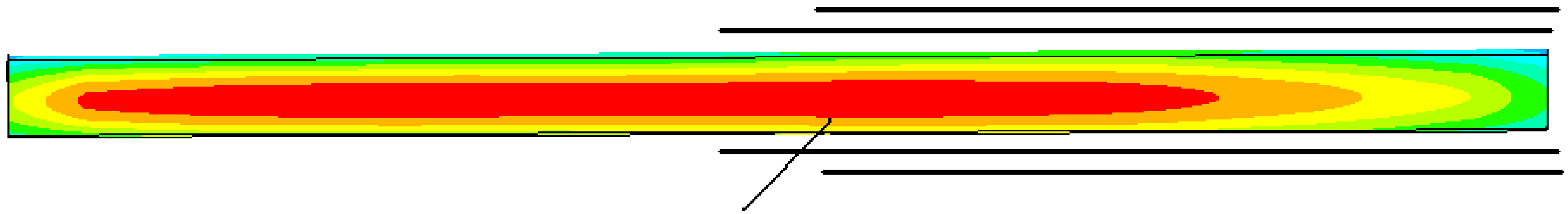


Temperature profile of the annular NbC/RVCF target with/without local thermal shielding. Rin: 6 cm; Rout: 10 cm; Length: 80 cm; Density: 1.2 g/cm³; 1 GeV, 400 kW convergent incidence proton beam

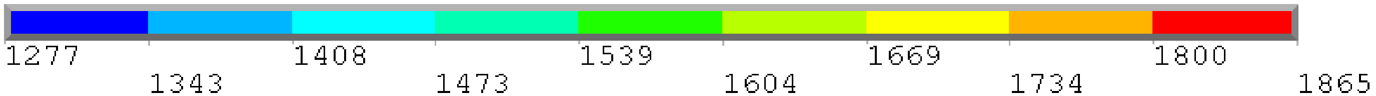


NbC/RVCF target without local thermal shielding

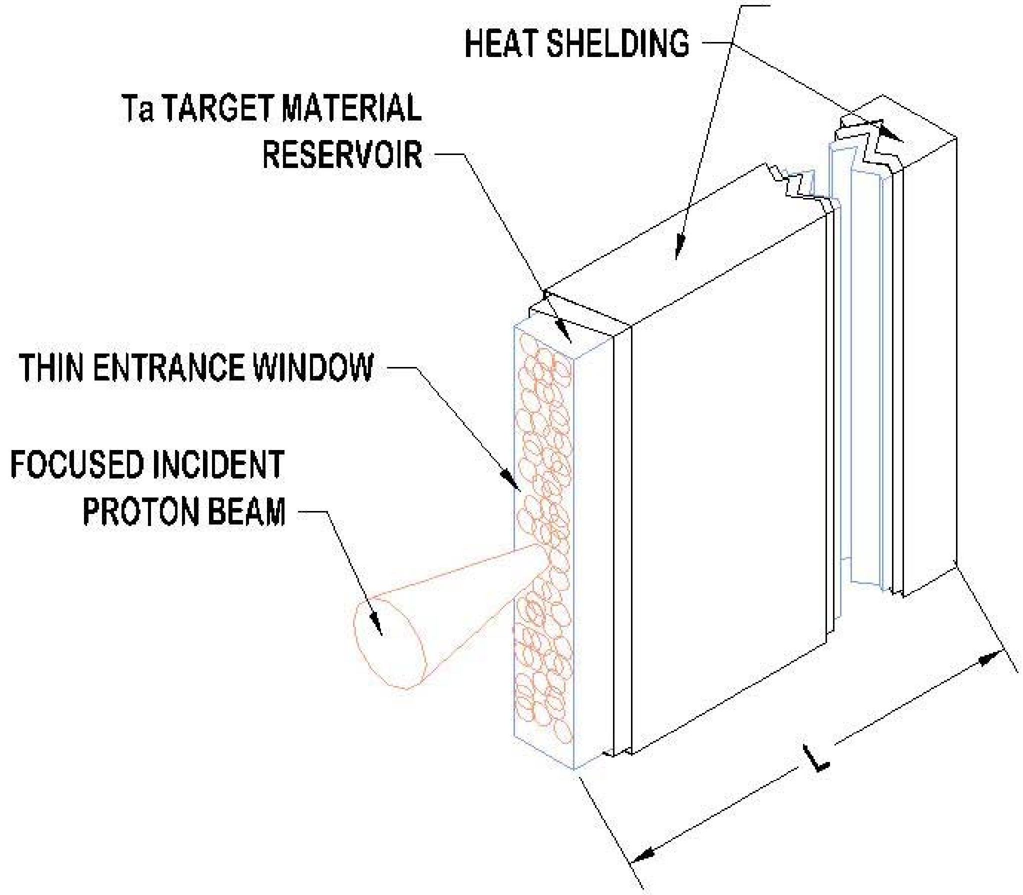




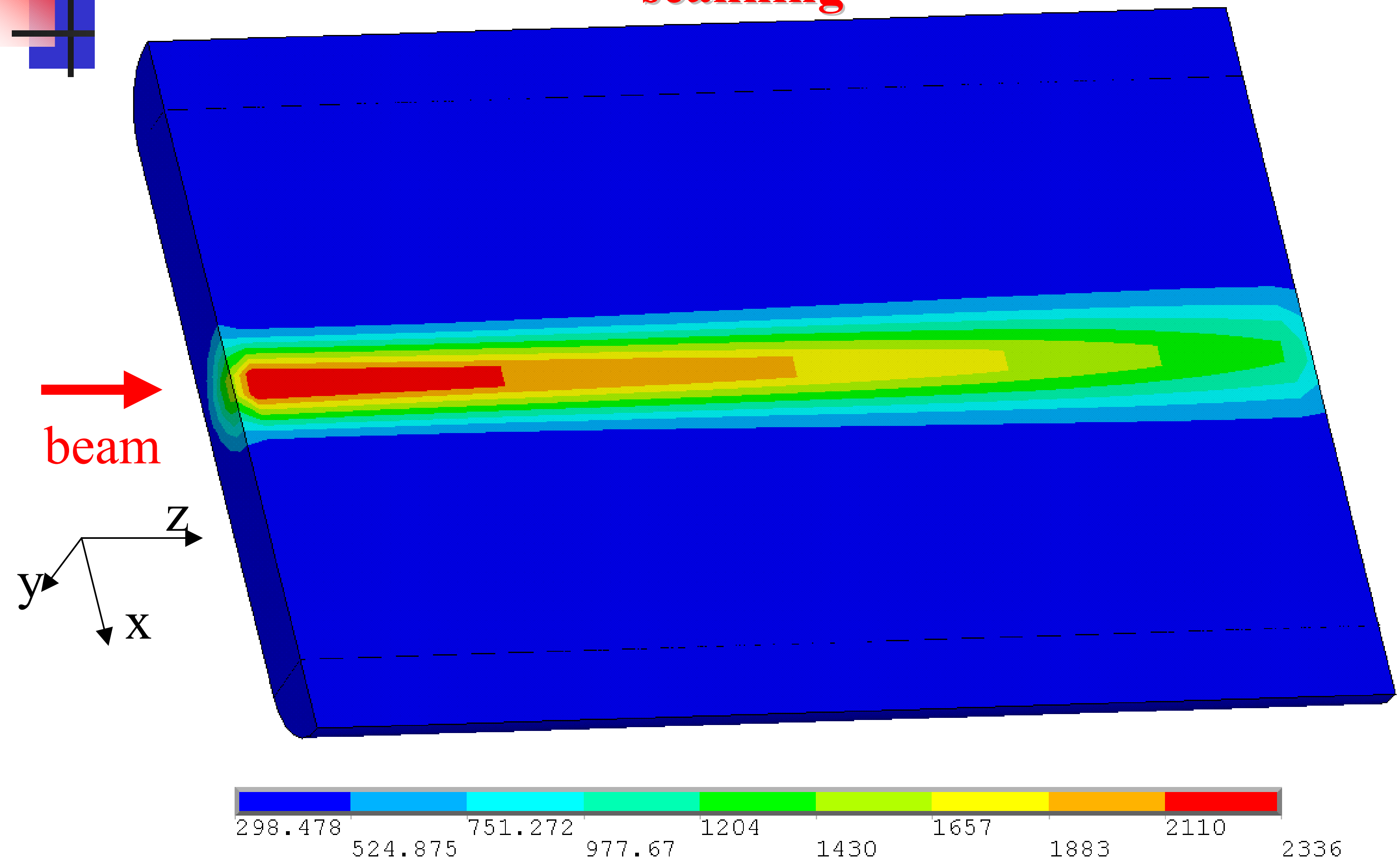
NbC/RVCF target with local thermal shielding



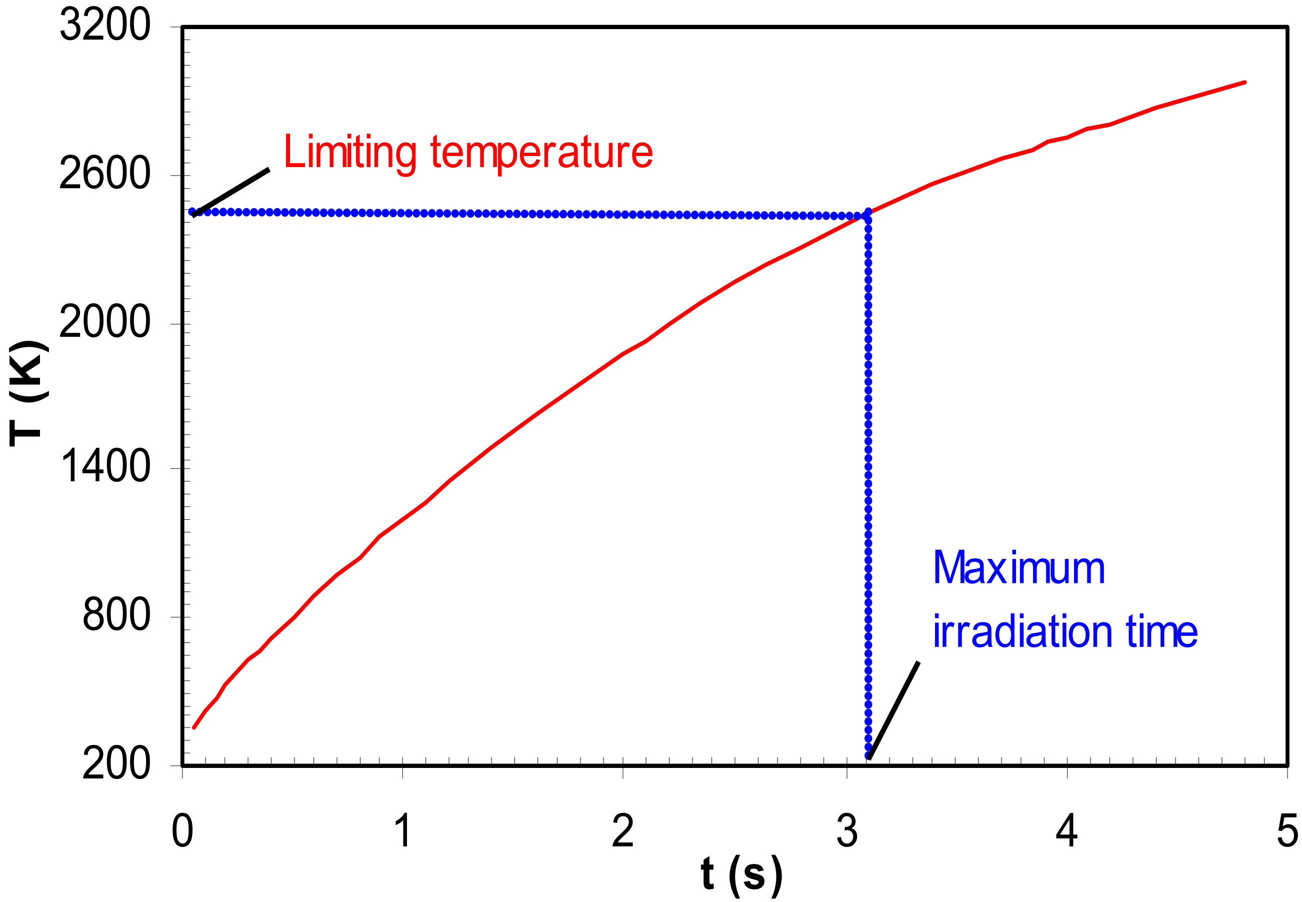
The Lissajous Scanning Technique Permits Target Direct Irradiation of Targets with RIA Power Level Beams (400 kW)



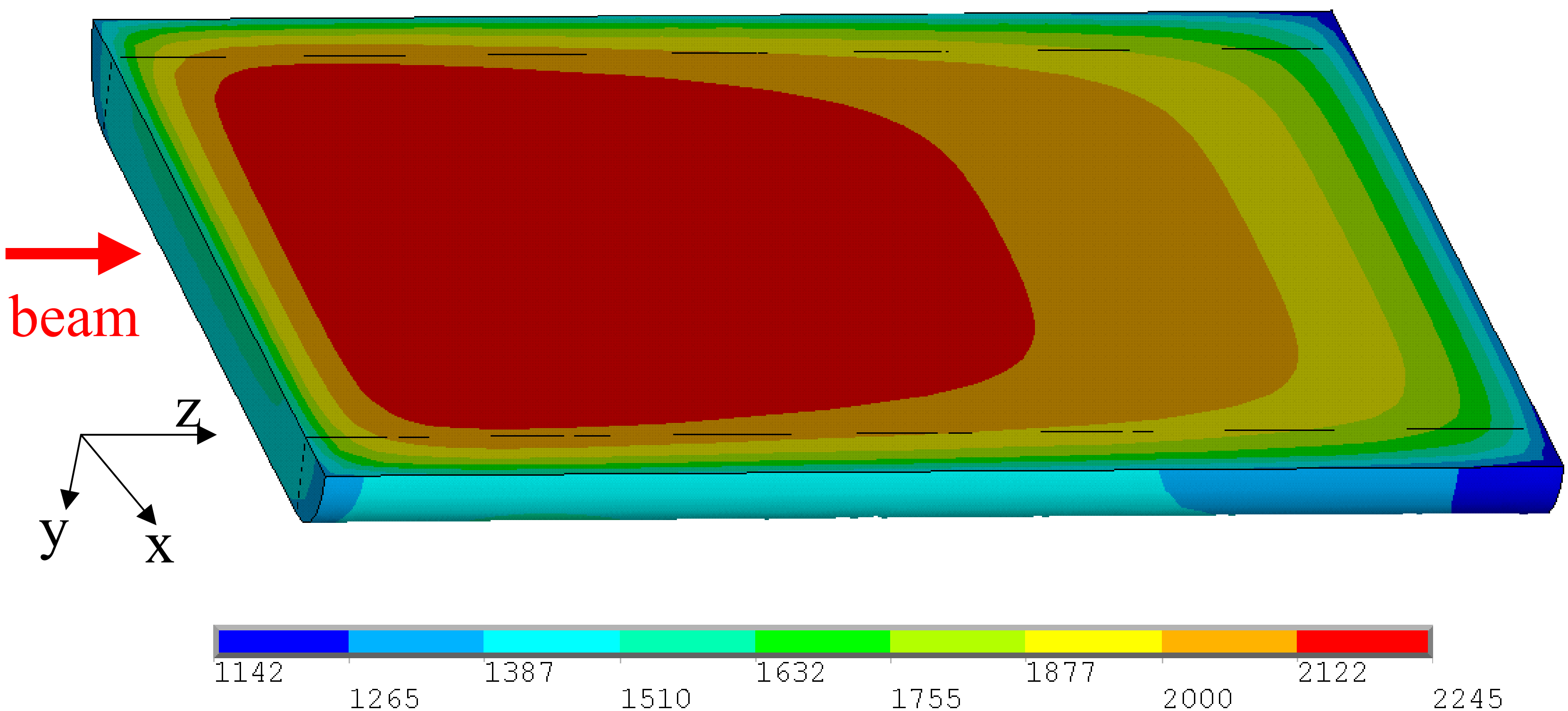
UC_2/6xRVCF target heated from room temperature by 1 GeV, 400 kW proton beam. Beam diameter: 1 cm; *t* : 2.8 s; no scanning



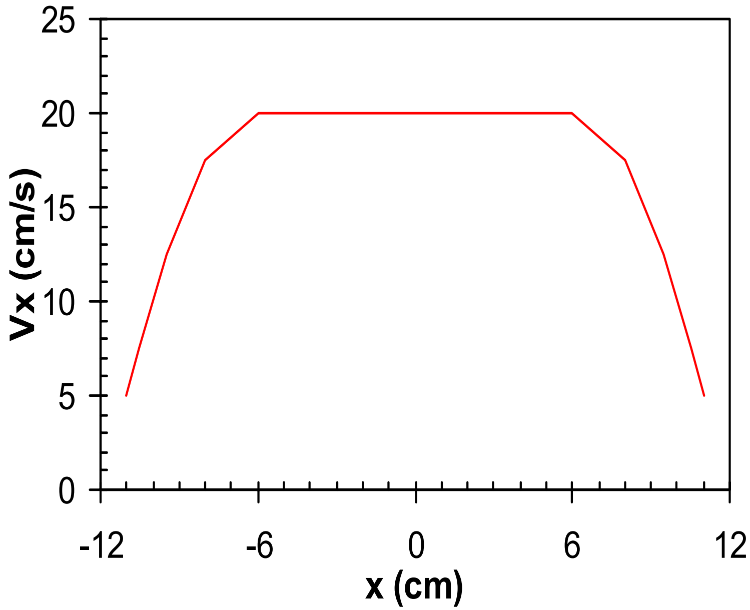
Maximum target temperature versus beam irradiation time; Beam: CW 400 kW proton.

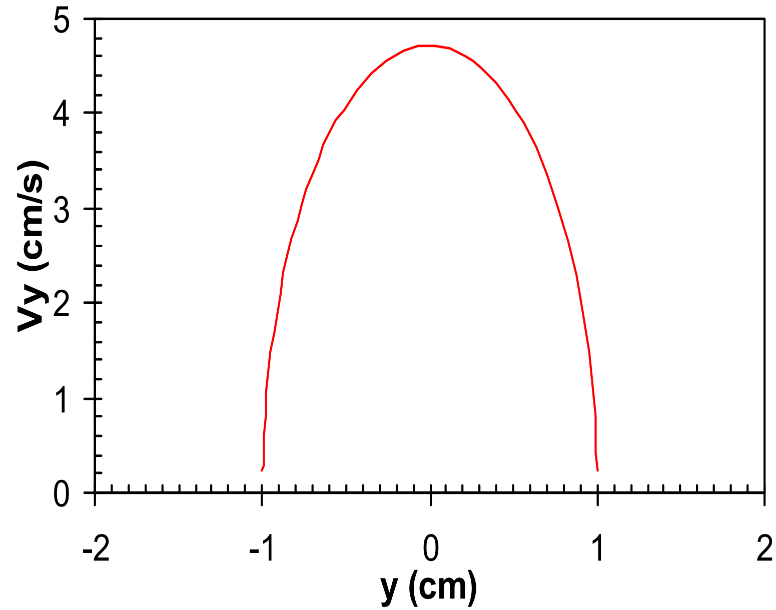


Average temperature of a UC_2/6xRVCF target irradiated with 1 GeV, 300 kW proton beam. Target: 24×4×30 cm^3; beam scanned along the 24 cm × 4 cm end; cooling: thermal radiation.

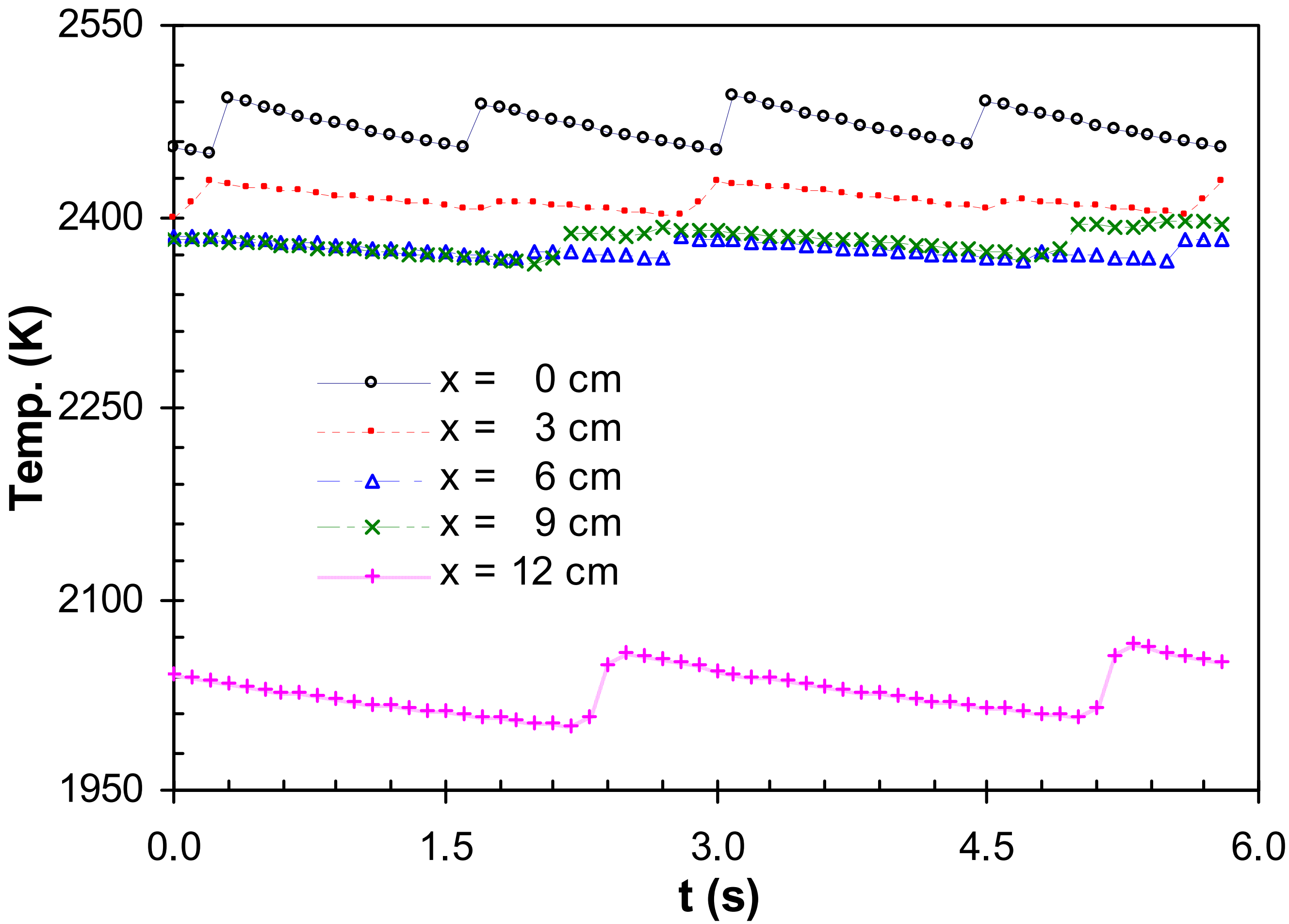


Beam scanning speed adjusted to more uniformly distribute target temperature





Temperature versus time along the x axis cut at y = 0, z = 7.5 cm. UC_2/6xRVCF target, 24×4×30 cm^3; 1 GeV, 300 kW proton beam; Scan period, along x: 2.8 s, along y: 1.3 s.



Summary

- Internal thermal radiation
  - is effective at elevated target temperatures and, thus,
  - provides an effective way to locally cool target materials.
- Use of additional thermal shielding on exit ends of targets
  - results in more uniform target temperature distributions over total target volumes.
- Beam manipulation/beam scanning techniques
  - permit more even distribution of beam deposited power within target volumes;
  - permit direct irradiation of fragile, low thermal conductivity targets with RIA power level beams (i.e., 400 kW).